UCRL-JRNL-221078

LAWRENCE LIVERMORE NATIONAL LABORATORY

High Bandwidth Data Recording Systems for Pulsed Power and Laser Produced Plasma Experiments.

MJ May, T Clancy, D Fittinghoff, C Halvorson, T MIlls, A Nikitin, T Perry, P Roberson, D Smith, A Teruya, K Miller, C Trainham

May 3, 2006

Review of Scientific Instruments

Disclaimer

High Bandwidth Data Recording Systems for Pulsed Power and Laser Produced Plasma Experiments.

M.J. May, T. Clancy, D. Fittinghoff, C. Halvorson, T. Mills, A. Nikitin, T Perry, P. Roberson, D Smith, A Teruya,

Lawrence Livermore National Laboratory, 7000 East Ave. Livermore, CA 94550

E.K. Miller and C. Trainham

Special Technologies Laboratory, Bechtel Nevada, 5520 Ekwill St., Suite B, Santa Barbara, CA 93111.

Abstract

We present two high bandwidth data transmission and recording systems for the measurement of transient signals during pulsed power and laser produced plasmas. These systems use fiber optic cables to transmit analog data over long distances to high bandwidth digitizing oscilloscopes. One system is based on the direct modulation of a laser diode and has a bandwidth of 1.5 GHz. The other system is based upon a fiber-optic Mach-Zehnder modulator and has a bandwidth of 12 GHz, and is limited by the photo receiver. The signals are recorded on commercial digitizing oscilloscopes that have approximately 6 effective bits. The transmission systems use many off-the-shelf components from the telecommunications industry and thus have a high reliability and a moderate cost. Results from recent measurements will be presented. Investigation of the reduction in optical transmission by the fibers during exposure to high dose radiation will also be discussed.

Introduction:

High energy density experiments at laser and pulsed power facilities create transient plasmas with durations of 1 to > 10 ns. Experimenters wish to measure the time history of the X-rays, gammas, etc. from the source with high bandwidths or with time resolutions of 0.1 ns or better[1 2]. The harsh environments of these facilities require that the recording systems be located some distance away from the plasma, to reduce noise. Additionally, prolonged exposure to the environment (neutrons flux, gamma flux, electromagnetic interference, etc.) could damage or destroy the recording systems. The distance between the detector and the recorder can be tens to hundreds of meters.

The data transmission can be accomplished by long runs of high bandwidth coaxial cable with diameters of greater than 1". Long cable runs are not without problems. The cables must be properly equalized to maintain a flat frequency response both in amplitude and phase. However, the attenuation of a highly compensated cable will significantly reduce the dynamic range of the system. In pulse power applications, copper cable penetrations of EMI enclosures can add noise to the recorded signal. These effects make the measurement of weak signals more difficult. Additionally, the grounding of long cables at high frequencies can be problematic.

In this paper, two high bandwidth data transmission and recording systems are presented that use fiber optic cables to transmit analog data over long distances (100 m) to high bandwidth digitizing oscilloscopes. Fiber optic modulators are a robust way to transmit high bandwidth data over long distances with little loss of signal fidelity. One system is based on the Direct Modulation (DM) of a laser diode and has a bandwidth of ~ 1.5 GHz. The other system is based upon a Mach-Zehnder (MZ) modulator and has a bandwidth of 12 GHz, limited by the photo receiver.

Direct Modulation

A schematic of the DM system is shown in Fig. 1. DM fiber optic transmitters are attractive due to their simplicity. The laser transmitter employs a CW laser, and its amplitude is modulated by varying the input drive current. The laser is about the size of a bottlecap, and the necessary thermo-electric cooler, electric power supply, and control circuitry can be packaged into a unit the size of a brick. A commercially available DM transmitter made by Pulse Power Measurements Inc. was tested and operates at 1310 nm. This unit has a 1.5 GHz bandwidth, with a 2 kHz lowpass cutoff. The manufacture specifications list 1.35 GHz as the bandwidth. The maximum input voltage for the unit is 250 mV. The transmitter link without a recorder has a flat response in signal amplitude (+/-1 dB) as a function of frequency with a 3 dB point at 1.8 GHz. The phase response is flat to 1.5 GHz with a variation of < 15° from 10 MHz to 1.5 GHz. The link has a dynamic range of 50 dB (~ 8 bits) from a 107 mV signal to the link noise level. The linearity is better than ±1% with a signal up to 224 mV.

The choice of fiber optic cable for both the DM and MZ modulators was single mode SMF-28 by Corning Inc. that can be used at either at 1310 and 1550 nm. These wavelengths are commonly used by the telecommunications industry. The fiber has a core diameter of 10.5 μm with an outer diameter of 125 μm. The attenuation is 0.2 dB/km at1550 nm. The dispersion is 18 ps/nm-km at 1550 nm.

The recorder for the DM link, a Tektronix TDS6604 digital storage oscilloscope, has a 6 GHz analog bandwidth. The analog to digital converter (ADC) has 8 real bits and can sample up to 20 GSamples/sec. The ADC has approximately 6 effective bits at the full sampling rate and limits the dynamic range of the system to 28 dB. More of the dynamic range of the link can be recovered (about 36 dB) by the splitting signal in half after the photo receiver (see Fig. 1). One half of the signal is directly digitized. The other half is amplified by 22 dB and then digitized.

Mach-Zehnder

The MZ[3] interferometer uses high-quality commercially available components in a configuration that allows simple, compact, low-power designs. Many of the components are designed for the military and aerospace in addition to telecom infrastructure, so they are environmentally ruggedized against temperature, humidity and radiation (low-level continuous dose). These components are ideal for the radiation environments of laser produced plasmas and pulsed power experiments. Each transmitter is about the size of a shoebox. Currently available components make assembly and operation of a MZ link very simple. Diode lasers are powerful, stable and compact, with polarization-maintaining (PM) fiber pigtails, and modulators are designed specifically to couple to off-the-shelf lasers with PM fiber pigtails. Photoreceivers and amplifiers are available with excellent phase response for short pulse duration experiments.

A MZ system that is capable of a 12 GHz bandwidth is shown in Fig. 2. The MZ fiber optic transmitter uses an external modulator to attain the greatest possible bandwidth. This system uses a continuous wave distributed feedback diode laser as the light source at 1550 nm, and a lithium niobate MZ modulator. A narrow linewidth laser minimizes the effect of chromatic dispersion in the optical fiber. A Photonic Systems, Inc., bias controller serves to correct for temperature induced drift in the bias point of the MZ. The laser has a thermo-electric cooler operated in a closed loop to maintain a fixed output intensity. The response of the link in amplitude as a function of frequency has its 3 dB point at 12 GHz. The phase is very flat to greater than 12 GHz with a small, low frequency error.

The transfer function of the MZ interferometer is sinusoidal (Fig. 3). As the input signal is increased the output will vary as a sine function between the minimum and maximum output of the modulator. The MZ can be operated in two different modes, the quasi-linear and sinusoidal modes. In quasi-linear mode the output signal is roughly a linear function of the input signal because it is the region of maximum change of the sine function between extrema. The dynamic range is approximately 35 dB with a deviation in linearity of about 5%. In the sinusoidal mode, the MZ modulator passes through multiple fringes and has a dynamic range of greater than 59 dB. In this mode, for every complete fringe the modulator passes through requires twice the recording bandwidth of the previous fringe.

The choice of bias point is important to obtain maximum signal fidelity. The bias point is the location of the transfer function that corresponds to zero signal on the high bandwidth electrical input. The commonly used bias points are at the minimum of the sine function, MIN, and in the region of the maximum slope of the sine function, Quadrature. The points of minimum sensitivity are the extrema of the sine function as there is little change in amplitude for a given change in signal. To obtain the maximum fidelity it is advisable to place the signal of interest away from these points. For the sinusoidal mode, the signal will cross through the points of minimum fidelity. To overcome this problem the signal is split and transmitted by two MZ systems set at MIN and Quadrature bias, respectively. The two signals will be 90° out of phase, and this will insure that one signal will have good fidelity while the other one is passing through an extrema.

The MZ link signal is recorded by a Tektronix TDS6124, 12 GHz analog bandwidth digital storage oscilloscope. The TDS6124 has an 8 bit ADC with approximately 6 effective bits at the maximum sampling rate of 40 GSample/sec. As seen with the DM system, the recorder limits the dynamic range to approximately 28 dB. The addition of an amplified channel increases the dynamic range to approximately 36 dB.

Fiber Optic Darkening

Fiber optic cable will darken after exposure to short intense radiation pulses such as those found in laser produced plasmas and pulse power experiments. Gamma rays entering a material will create Compton scattered electrons. These electrons deposit much energy in the material and are a source of much of the damage and darkening. The darkening can be transient or more permanent and will alter the performance of fiber optically based analog transmission systems. Attenuation measurements on currently available commercial fiber optical cable were performed at Bechtel Nevada Special Technologies Laboratory, Santa Barbara[4,5]. The SMF-28 fibers were exposed to electrons having energies of 2.2 MeV for 50 ns created with the Febetron 705 and 600 keV for 3 ns created with the Febetron 706 pulsed electron source. Total absorbed doses were in the 10 to 1000 kRad range. Typical transient changes in the transmissions of several fibers are presented in Fig. 4 at different levels of total absorbed dose. Changes of up to 10 dB per meter were observed for 1 Mrad doses. The recovery times could be as long as 1 ms.

Acknowledgements

This work was performed under the auspices of the U. S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

Figure #1:

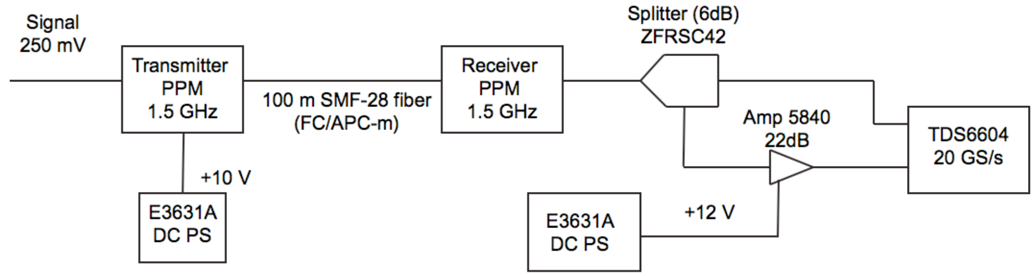


Figure #2:

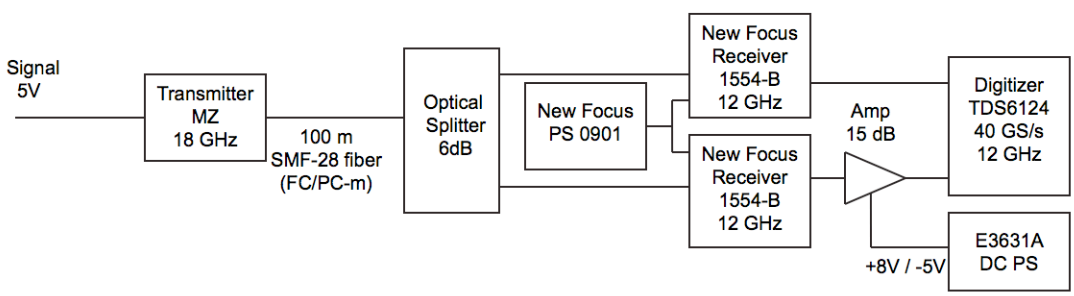
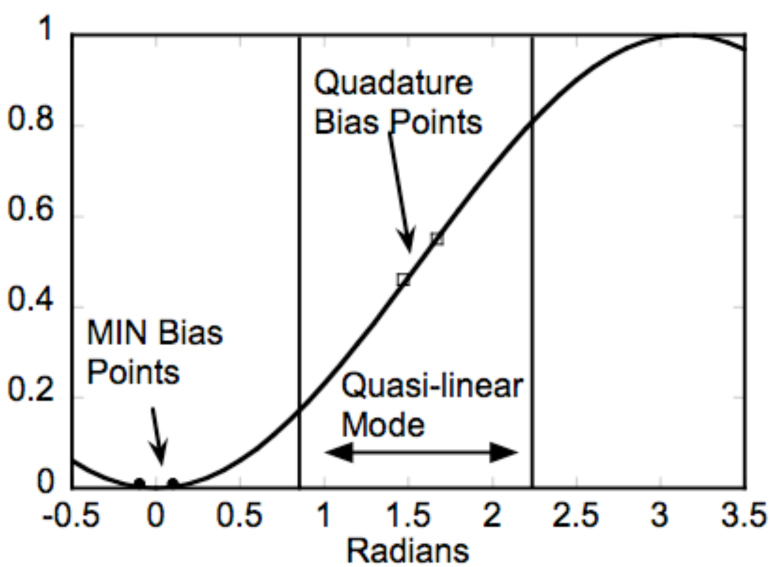
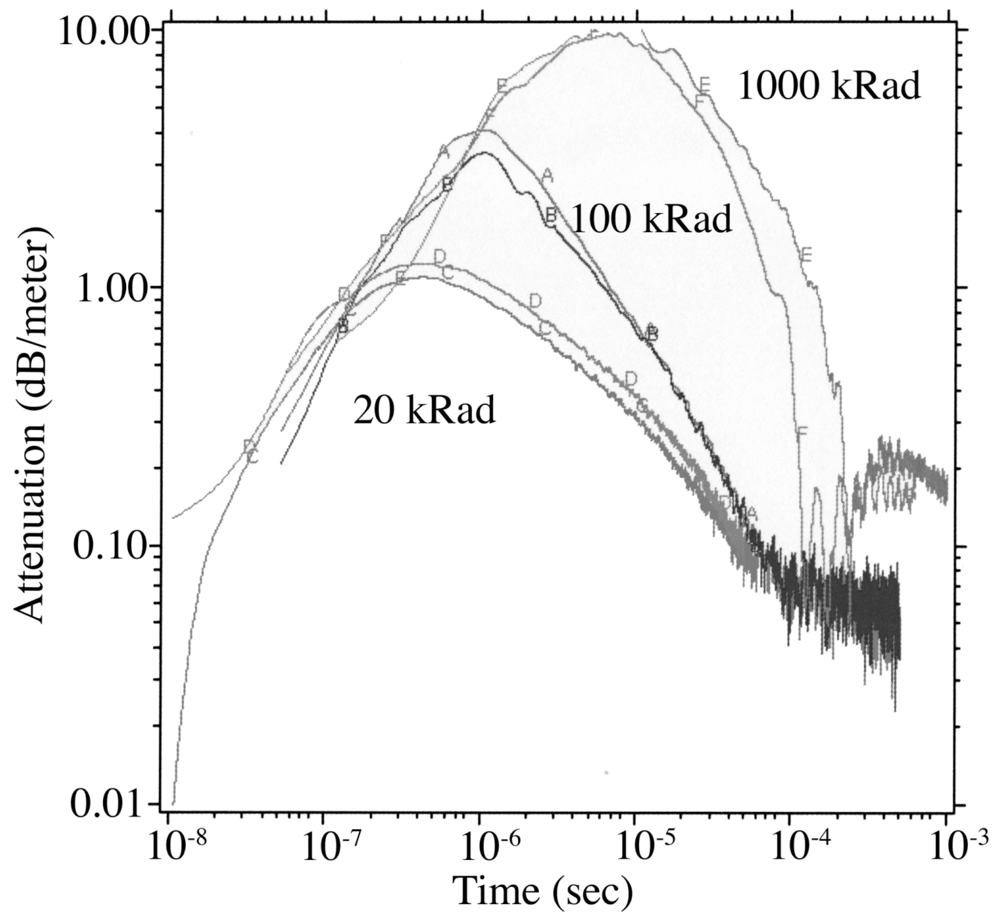


Figure #3:



Quadature
Bias Points
MIN Bias
Points
Quasi-linear
Mode
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
Radians

Figure #4:



10.00
1.00
0.10
0.01
Attenuation (dB/meter)
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
Time (sec)
1000 kRad
100 kRad
20 kRad

Figure Captions:

Fig. 1: Design of a Direct Modulation data transmission system

Fig. 2: Design of a Mach-Zehnder data transmission system

Fig. 3: Sample transfer MZ transfer function showing typical MIN and Quadrature bias and the Quasi-linear mode region.

Fig. 4: Comparison of attenuations due to radiation exposure in dB/meter for 6 different shots (A to F) at three different dose levels (20 kRad, 100 kRad, 1000 kRad).

References:

[1] D. E. Hinkel, M. B. Schneider, B. K. Young, et al, Phys Rev. Lett. accepted March 2006.

[2] M. Derzon, et. al., Review of Scientific Instruments, Vol. 70, 1, 566 (1999).

[3] C. D'hose, E. Cassan, J. Baggio, et al., IEEE Transactions on Nuclear Science, Vol. 45, No. 3 (June 1998).

[4] E. Friebele, P. Lyons, J. Blackburn, Journal of Lightwave Technology, Vol. 8, No. 6, (June 1990).

[5] M.D. Rotter and D.R. Jander, Proceedings of the SPIE, Vol. 506, pp18-21 (1984).